

ORIGINAL STUDY

HARDNESS AND POST-SCRATCH SURFACE MORPHOLOGY OF Cr_3C_2 -NiCr COATINGS AFTER ULTRASONIC NANOCRYSTAL SURFACE MODIFICATIONA.Y. Kussainov¹, I.K. Abizhanova¹, M.T. Kaliaskarova¹, Y.S. Molbossynov¹, N.M. Magazov¹¹D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan*Corresponding author: mkaliaskarova@edu.ektu.kz

Abstract. The hardness and post-scratch surface morphology of Cr_3C_2 -NiCr coatings subjected to ultrasonic nanocrystal surface modification (UNSM) were examined for detonation-sprayed (DS) and high-velocity oxy-fuel (HVOF) deposits. Four treated samples per deposition route were evaluated at static loads of 20 and 30 N and vibration amplitudes of 20 and 30 μm . Instrumental hardness was measured at a load of 300 mN with a dwell time of 10 s. The DS samples exhibited hardness values of 820–970 HV, whereas the HVOF samples covered the wider range of 546–1165 HV. The highest values were recorded for DS-T1 at 20 N/20 μm and HVOF-T4 at 30 N/30 μm . SEM fields acquired after scratch testing showed heterogeneous surface contrast and crack-like discontinuities in both coating series. These observations provide qualitative evidence of the post-test surface condition but do not isolate damage caused by UNSM or establish a ranking of scratch resistance. Available mean friction coefficients are reported as supplementary observations for six treated samples. The results demonstrate a sample-dependent hardness response and emphasize the need to assess local mechanical properties together with surface integrity.

Keywords: Cr_3C_2 -NiCr; detonation spraying; HVOF; ultrasonic nanocrystal surface modification; instrumental hardness; scanning electron microscopy; scratch damage.

1. Introduction

Cr_3C_2 -NiCr coatings combine hard chromium-carbide particles with a metallic binder and are used to protect surfaces exposed to sliding and abrasive contact. Their response depends on how the carbide phase is supported within the deposited structure. In HVOF- and HVOF-sprayed chromium-carbide coatings, the cohesion within and between deposited regions influences fragment removal and carbide pull-out during wear [1]. The deposition route and its operating parameters therefore affect the performance of the coating as a composite, beyond the hardness of its individual constituents. For detonation-sprayed Cr_3C_2 -NiCr, changes in barrel filling have been shown to alter phase composition, hardness and tribological response [2].

Post-deposition treatment offers an additional means of modifying this structure. For example, pulse-plasma treatment of detonation-sprayed Cr_3C_2 -NiCr produced changes in phase composition and surface morphology together with increased hardness and wear resistance [3]. Such results demonstrate the potential of post-treatment, while also showing that its effect must be assessed for the particular coating and processing method. Thermal modification and repeated mechanical impact act through different pathways; improvements obtained with one treatment do not establish the outcome of another.

Ultrasonic nanocrystal surface modification (UNSM) applies repeated impacts through a contacting tool under a static load. Research on thermally sprayed ceramic coatings has examined changes in hardness, roughness and resistance to adhesive failure following this treatment [4]. More directly relevant studies of HVOF Cr_3C_2 -NiCr have investigated its friction and wear in fuel-lubricated contacts [5] and its scratch response after UNSM [6]. These studies motivate the use of ultrasonic treatment for chromium-carbide

coatings, but also highlight the importance of considering several responses. A mechanically modified binder and a carbide-rich region need not accommodate repeated contact in the same manner.

Hardness and resistance to cracking address complementary aspects of coating performance. Indentation characterizes local resistance to penetration, whereas scratch testing introduces a moving contact and allows examination of cracking and other damage along the loaded region. Work on HVOF Cr_3C_2 -NiCr-based coatings with cobalt additions has used scratch morphology and critical loads to characterize failure [7]. Dynamic impact studies of chromium-carbide coatings have likewise related contact durability to the binder and deposited microstructure [8]. These findings support combining hardness measurements with observations of damage, rather than using maximum hardness as the sole criterion for post-treatment selection.

The present study examines the hardness and qualitative resistance to cracking under scratch loading of UNSM-treated DS and HVOF Cr_3C_2 -NiCr coatings. Static loads of 20 and 30 N and vibration amplitudes of 20 and 30 μm are considered. SEM observations are used to describe the post-scratch crack morphology, while published as-sprayed hardness values [9] provide reference context. Available friction coefficients are included as secondary observations. The objective is to establish the measured hardness response across the treated samples and describe the accompanying damage morphology without equating qualitative scratch observations with a measured fracture-toughness parameter.

2. Materials and methods

2.1. Coating preparation and reference states

Cr_3C_2 -NiCr deposits were produced by detonation spraying using a CCDS2000 system and by propane-fuelled HVOF spraying. The recorded HVOF settings were a propane pressure of 2.9 bar, oxygen pressure of 5.0 bar, compressed-air pressure of 3.2 bar and a spraying distance of 200 mm.

2.2. Ultrasonic treatment conditions

The treatment system used a nominal vibration frequency of 20 kHz, a spherical-ended hard-alloy tool and pneumatic application of a static load. The process geometry is illustrated in Fig. 1. Sample codes DS-T1–DS-T4 and HVOF-T1–HVOF-T4 identify the treated coatings by deposition route. The suffix identifies a specimen, not a unique load–amplitude combination. The documented amplitudes and static loads are listed in Table 1. The condition number is an identifier and does not represent a monotonic increase in treatment intensity.

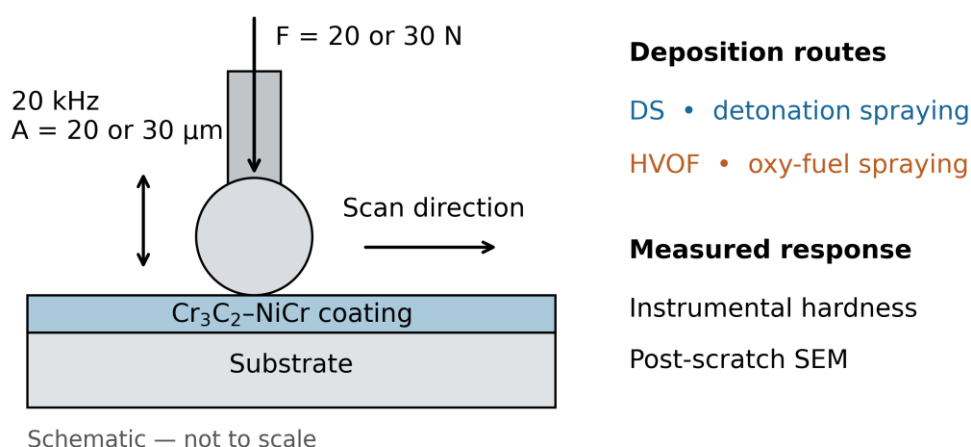


Fig. 1. Schematic of the UNSM contact and the two deposition routes. The drawing illustrates the process geometry and is not to scale.

Table 1. Sample designation and UNSM parameters for Cr₃C₂-NiCr coatings.

Sample	Route	Static load (N)	Amplitude (μm)
DS-T1	DS	20	20
DS-T2	DS	30	20
DS-T3	DS	20	30
DS-T4	DS	20	30
HVOF-T1	HVOF	20	20
HVOF-T2	HVOF	30	20
HVOF-T3	HVOF	20	30
HVOF-T4	HVOF	30	30

2.3. Mechanical and tribological characterization

Instrumental hardness was characterized using a FISCHERSCOPE HM2000 system controlled by WIN-HCU software. The applied indentation load was 300 mN with a dwell time of 10 s. The general coating characterization procedure involved indentation of polished cross-sections and averaging at least ten measurements per specimen. Scratch testing followed by scanning electron microscopy was used for a qualitative assessment of coating resistance to crack initiation and propagation under a moving contact. Eight fields were associated with the treated samples, with one field per sample. These images document the post-scratch condition rather than the surface immediately after UNSM. Original image fields and scale bars were retained. The images were assessed qualitatively for surface heterogeneity and visible discontinuities; no quantitative grain-size, porosity or crack-density analysis was performed. Supplementary dry sliding measurements were obtained at room temperature using an Anton Paar TRB³ tribometer in a ball-on-disc configuration.

3. Results and discussion

3.1. Hardness response to ultrasonic treatment

Figure 2 shows the hardness values of both coating series. The four DS conditions yielded 970, 860, 930 and 820 HV for T1–T4, respectively. The maximum occurred at T1 and the minimum at T4, with an overall span of 150 HV. T2 and T3 differed by 70 HV. Since their amplitude and load change simultaneously, this difference cannot be attributed to either parameter alone.

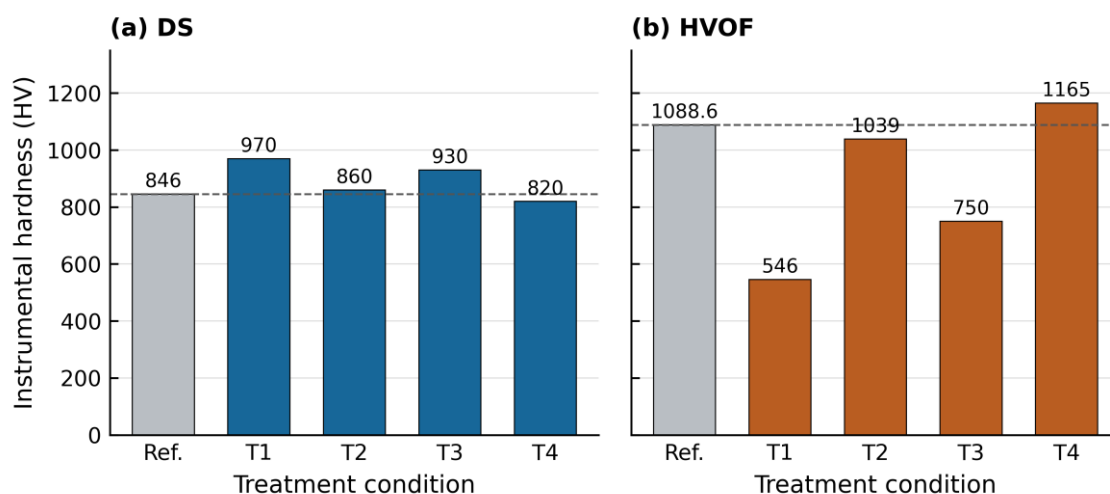


Fig. 2. Instrumental hardness for (a) DS and (b) HVOF coatings. Grey bars and dashed lines identify published as-sprayed references [9]; coloured bars represent the UNSM conditions.

The HVOF series yielded 546, 1039, 750 and 1165 HV for T1–T4. The range across the four conditions was 619 HV, substantially wider than the DS range. This is variation between processing conditions; it must not be confused with repeatability or scatter within a condition. The maximum HVOF hardness was measured at T4, despite the large hardness reduction observed at T1.

The published reference hardness values were 846 HV for DS and 1088.6 HV for HVOF [9]. Three treated DS samples were numerically above the DS reference, while only HVOF-T4 exceeded the HVOF reference. These comparisons do not establish an optimal setting. DS-T3 and DS-T4, both recorded at 20 N/30 μm , yielded 930 and 820 HV, respectively; the available record does not establish their status as independent processing replicates. Their different results prevent assigning all variation solely to the two listed treatment parameters.

A possible interpretation is competition between plastic deformation of the binder and accumulation of damage in the composite. Both the carbide distribution and cohesion between deposited regions can influence how repeated impacts are accommodated. This interpretation is consistent with the importance of cohesion in chromium-carbide coating wear [1], but the present hardness data alone do not identify a fracture mechanism. No quantitative grain-size, residual-stress or porosity measurements are used here to claim nanostructuring or densification.

3.2. Qualitative assessment of cracking resistance by scratch testing

Figure 3 presents the available SEM fields for all eight treated samples. Both series display spatially heterogeneous contrast with irregular dark discontinuities. Crack-like lines are visible in multiple HVOF and DS fields, including branched or intersecting features. Their appearance varies from one field to another. Dark regions alone cannot be identified unambiguously as open pores, detached material or compositional contrast without additional imaging or local chemical analysis.

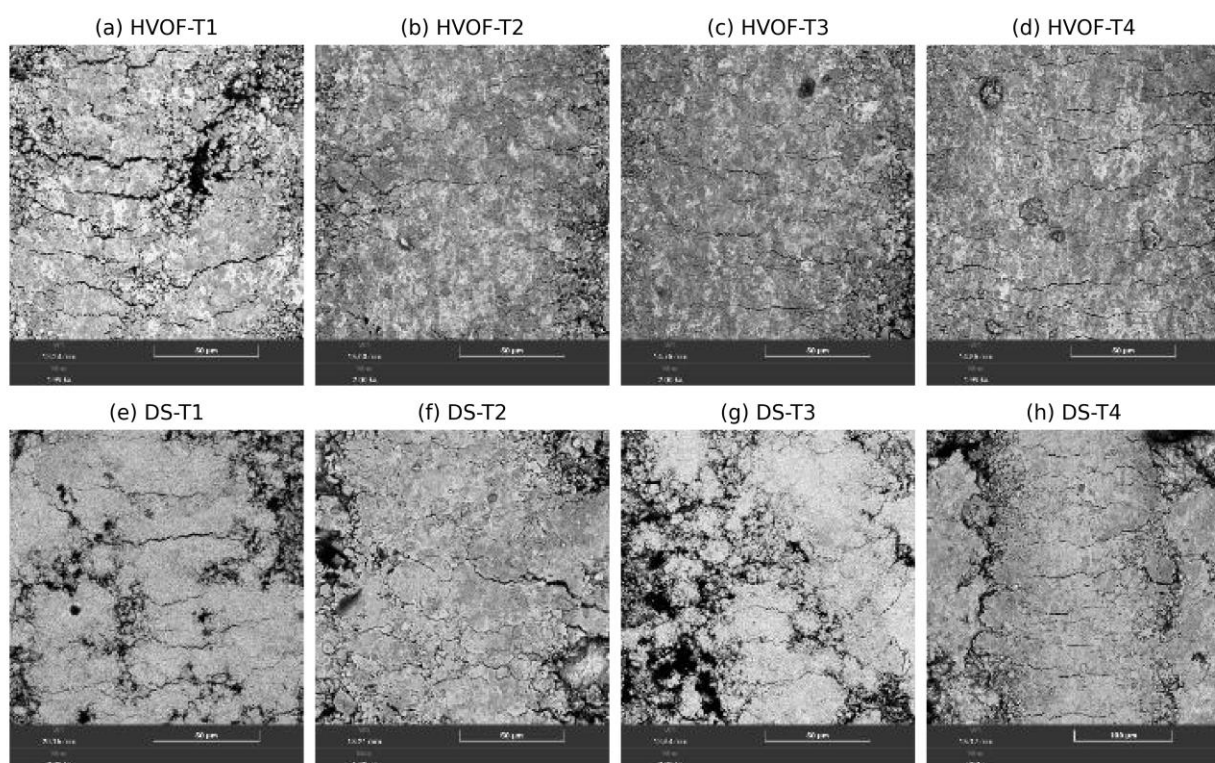


Fig. 3. SEM fields of Cr_3C_2 –NiCr coatings after scratch testing: (a–d) HVOF-T1–HVOF-T4 and (e–h) DS-T1–DS-T4.

Scratch-induced damage is evaluated here through the continuity, branching and spatial distribution of visible cracks. Extended crack-like features and locally connected discontinuities occur in the presented fields, indicating that cracking contributes to the response of both coating series under mechanical contact.

Differences between individual fields describe local damage morphology; they are not sufficient to rank the resistance to cracking of entire coating series.

3.3. Supplementary friction observations

The available mean friction coefficients are listed in [Table 2](#). The measured values span 0.678–0.726 for DS and 0.711–0.757 for HVOF. HVOF-T4 has the highest measured hardness and the highest available friction coefficient within its series, so the two criteria do not give the same sample ranking.

Table 2. Available mean friction coefficients after UNSM. NR denotes an unreported value.

Sample suffix	DS	HVOF
T1	0.678	NR
T2	NR	0.722
T3	0.726	0.711
T4	0.717	0.757

Published studies of UNSM-treated Cr_3C_2 –NiCr coatings under fuel-lubricated sliding [5,6] provide relevant context but involve a different contact environment. Their reported improvements cannot be transferred directly to the present observations.

4. Conclusion

The hardness, post-scratch surface morphology and frictional response of UNSM-treated Cr_3C_2 –NiCr coatings produced by detonation spraying and HVOF spraying were examined. The following conclusions were drawn:

1. The DS coatings exhibited hardness values of 820–970 HV, whereas the HVOF coatings showed a wider range of 546–1165 HV. The highest hardness in the DS series was 970 HV for DS-T1, treated at a static load of 20 N and a vibration amplitude of 20 μm . For HVOF coatings, the highest value was 1165 HV for HVOF-T4, treated at 30 N and 30 μm . These results demonstrate that the hardness response across the investigated treatment conditions differs between the two deposition routes.
2. SEM examination after scratch testing revealed crack-like discontinuities with varying continuity, branching and spatial distribution in both coating series. Extended and interconnected features characterized the local damage patterns under scratch loading. The joint examination of these features provided a qualitative characterization of cracking behaviour and complemented the hardness measurements.
3. The measured mean friction coefficients ranged from 0.678 to 0.726 for DS coatings and from 0.711 to 0.757 for HVOF coatings. DS-T1 combined the highest hardness in its series with the lowest measured friction coefficient of 0.678. HVOF-T4 exhibited both the highest hardness and the highest friction coefficient in its series, at 0.757. Thus, the relationship between hardness and friction depended on the coating series and treatment condition.
4. The combined assessment of hardness, post-scratch morphology and friction distinguished the mechanical and contact responses of the treated coatings. DS-T1 showed a favourable combination of hardness and friction within the DS series, while HVOF-T4 achieved the highest hardness among all investigated specimens. These findings identify distinct property combinations for the two deposition routes and provide a basis for selecting treatment conditions according to the required coating response.

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Conflict of interest

The authors declare that they have no competing interests.

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